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Effect of various parameters on Spread in flashing operation of precision steel ball manufacturing process

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Abstract

Precision balls are the key elements for critical aeronautical bearings, guidance system balls for space and military applications, precision valves, automotive bearings and other applications. In all these applications higher precision is required. Hence, the development of a more economical finishing method becomes a critical problem in the application of advanced Steel ball manufacturing. Spread is the variation in the Diameter of Balls of same batch or lot. Spread is a very critical quality parameter which must be controlled while operation. The experiment for Flashing was designed using a full factorial design with two levels for each input variable (2^k factorial design). Since there are three factors, each at two levels, the design is 2^3 factorial designs. Factors taken for the experiments are Pressure between two plates, No. of Grooves in plates & RPM of Ring Plate. From the main effect plot pressure should be at lower level. Same way from RPM should be at lower level & No. of grooves should also be at lower level to achieve minimum spread. Also at these level of the parameters the residual (error) found from the regression model is -0.625 which is very less so the value of these parameters satisfying the required function. Also from the experiments Percentage contribution are pressure having 43.55%, No. of Grooves having 23.31% & RPM having 23.31% effect on spread.

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Keywords: Flashing, Spread, Design of experiment, ANOVA, regression model.

1. Introduction

1.1. Ball Manufacturing Process

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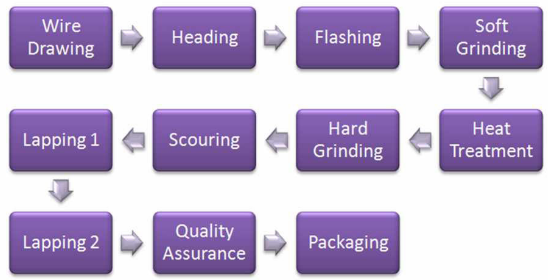

Fig 1 : Operation sequence for Precision Steel Ball Manufacturing

In wire Drawing Wire Coils are checked for Diameter and chemical composition. Annealing is one kind of Heat treatment process. In this Process the coils of wire will be put in the furnace & this process takes approximately 22 hrs. Then wire coil will be send to heading department. In heading, Wires are cold forged into spherical shapes between two dies. A process that produce slugs from raw wire and from slug headed ball will produce by cold forging. In Header Machine the Wire will be cut with cutter & the cut piece of wire is known as Slug. Size of the Slug is maintained by setting the stroke length of the cam & follower. After that Slug is pressed in Die with the help of Punch, so it will be formed in approximately round Shape. Headed blanks are ground between two metal plates. Flashing Operation is a process of removing excessive material of Ball or to remove the material at equator & Poll to make the circumference of the ball perfectly round. In Flashing both the Plates are made of Cast Iron. It is the same process as flashing for removing the material but the difference is only that the Gap plate is made of Cast iron but the Ball wheel is a Stone Wheel.

Heat treatment is a high temperature process that hardens the ball by subjecting a metal or alloy to controlled heating and cooling to improve hardness and other properties. Specially designed furnaces are used to harden the balls. In heat treatment process the balls are heated around 4 hrs in a furnace then they are dropped in to the Quenching Oil. Then Washing will be done. But due to quenching oil the balls are become brittle. To relieve stress from these balls tempering operation is done. Grinding process is the step in which precision diameter and sphericity is achieved. It is similar to flashing process for perfecting the sizing, sphericity & smooth surface finish. This process is same as Soft Grinding only difference is that in soft grinding the balls are soft but now they are hard. In grinding operation Polycool 86 is used as coolant liquid. In this process the bunch of balls are rotated in big barrel. Barrel's rpm is 7, which was fixed when balls will fall from maximum height in barrel. Scouring is done to hard the Ball outer casing. So this is known as Case hardening Process. Lapping is the same process as the grinding process. The Material removal rate is lower than the grinding. In Lapping 1 the Gap plate is of Cast Iron but the Ring Plate is made of Bakelite having 800 Grit. Techlap is used as coolant. A process that polishes the ball to a shiny finish and to the exact size required. In lapping 2 the difference is that the ring plate is made of Bakelite having 6000 grit. Due to higher Grit in plate the balls are having higher surface finish. In other words it is a Polishing Process. In this stage the Balls will get their desired size as per customer requirement.

The finishing process of steel balls can be divided into two steps, firstly rough lapping (grinding), and secondly fine lapping (polishing). In the first step − lapping, maximum material removal rate is the goal while achieving fairly good ball roundness and maintaining no consequent ball surface and subsurface damage. The first step is lapping in which most of the stock from the ball is removed at a higher material removal rate. The second step in the finishing process is polishing, in which the ball surface roughness, roundness, dimensional and geometric accuracy are achieved. The major concern of the current study is to investigate the performance of the Flashing machine in the initial stage. Flashing is an initial operation to generate spherical surface of Ball which requires higher pressure as compare to lapping. Lapping is a gentle, final operation commonly used with low speed and low pressure to generate ultra- fine finishes, extreme flatness or roundness, and critically close tolerances. However, the usual definition of lapping is the random rubbing of a part against a lap (usually of cast iron composition or another material that is softer than the part) using an abrasive mixture in order to improve fit and finish.

1.2. Literature survey

C.J. Evans et al., 2002 reviews the fundamental mechanisms of material removal in lapping and polishing processes and identifies key areas where further work is required. The four Process components: The work piece, Fluid, Granule, Lap. J. Kang et al., 2005 examined two types of HIPed Si3N4 bearing ball blanks with different surface hardness and fracture toughness were lapped under various loads, speeds, and lubricants using a novel eccentric lapping machine in Examination of the material removal mechanisms during the lapping process of advanced ceramic rolling elements. In which the lapped surfaces were examined by optical microscope and SEM. Different lapping fluids affected the material removal rate at lower lapping loads, but they had much less influence on the material removal rate at higher lapping loads. The preliminary conclusion is that the material removal mechanism during the lapping process of silicon nitride balls using this eccentric lapping machine is mainly mechanical abrasive wear. J. Kang et al., 2001 design of a novel eccentric lapping machine for finishing advanced ceramic balls. Two kinds of HIPed (Hot isostatically Pressed) silicon nitride ball blanks (13.25 mm ~ 13.50 mm in diameter) were lapped and polished to 12.700 mm using this machine. A maximum material removal rate of 68 µm per hour was achieved at the lapping step, which is much higher than by the traditional concentric lapping method. The polished ball surface roughness Ra value is 0.003 µm, and the ball roundness is 0.08~0.09µm which is above grade 5, and close to grade 3 of the precision bearing ball specification. J. Kang et al., 2001 examined the cost of finishing operation is very much higher so Parameter optimization by Taguchi Methods for finishing advanced ceramic balls using a novel eccentric lapping machine is done. T. Kurobe et al., 1997 identify that low-order-waviness is improved when both the fixed lap and rotating lap have deep grooves. The medium-order-waviness is improved when the fixed lap has deep grooves, while the rotating lap has shallow grooves. The high-order-waviness is also improved effectively when the grooves on the fixed lap are deep, and the grooves on the rotating lap are shallow. J. Kang at al., 2003 suggests that in order to obtain better surface quality, the diamond particle size should be reduced gradually in previous lapping process, to avoid leaving any deep scratches on the ball surface.

2. FLASHING OPERATION:

Flashing is an initial operation in the ball manufacturing Process, this operation is followed by Heading Operation. Headed balls are operated between two metal plates. Headed balls are not perfectly round, balls are having different diameter at poll & Equator as shown in figure 2. Flashing operation is carried out to make the geometry of ball perfectly round. Flashing operation generates spherical.

Fig 2 : Headed Ball

Hydraulic unit is used to create pressure, that unit is installed behind the Gap plate (Fix Plate). Belt & pulley drive is used to connect the shaft & motor. The ring plate will be mounted on the shaft. Conveyor is used to feed the balls, which is also mounted on another motor. Bring both the plate nearer just to leave enough gap between the plates as required ball size. Feed balls in the grooves manually and rotate the plate in inching the m/c till the balls coming out from the out let chute with minimum pressures. Check the balls coming out from stopper box for any type of damage. If found ok than close the plate guard and Start the conveyor, coolant flow, oil pump and main motor. Set the coolant flow & run the machines ensuring that the balls are feed without any interruptions. Set the conveyor speed to facilitate smooth and uniform feeding.

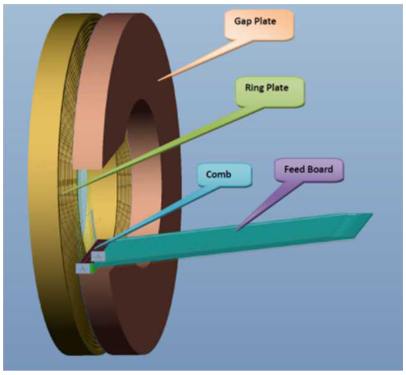

Fig 3: Model of flashing machine


Fig 4: Flashing machine

3. DESIGN OF EXPERIMENT

The DOE is divided into three main phases which encompasses the experimentation. The three phases are
1) Planning Phase
2) Conducting Phase
3) Analysis Phase
DOE in Flashing:

The process of Flashing is considered as an art because of the large amount of variability and subjectivity involved. Highly inconsistent results of flashing quality are due to variability in operators. The material removal rate, surface finish, and spread depend on the proper control of flashing parameters such as flashing pressure, flashing speed of rotation, Number of groove, flash ring material, weight and size, abrasive size and type, work piece material, coolant type and hardness. It is imperative to select proper values for the flashing control parameters to attain the desired outcomes.

Table 1: Parameters of operation

Controllable Parameters	Plate RPM, No. Of Grooves, Groove Depth, Flashing Pressure, Coolant Type & Temperature, Abrasive Grit size, Size of Plates etc
Response Parameters	Material Removal Rate, Spread, Flashing Cycle time, Surface Roughness

Factorial designs have been found to be most efficient for experiments that involve the study of the effects of two or more factors, which is the case here. Thus, in this research, the experiments were designed using factorial design concepts.

Objectives of the Experiment

The following are three main objectives of conducting a set of experiments for manual lapping:

- Explore the fundamental relationships among key parameters of flashing in a scientific approach.
- Gather data on the most critical parameters for a given set of product constraints.
- Use analysis of the results as a source of supporting information for understanding Flashing parameters and their relationships.

3.1 Parameters under Consideration:

The following sub-sections explain the parameters under consideration in conducting Flashing experiments by classifying them into uncontrollable, controllable, and response parameters.

Uncontrollable Parameters

The following parameters are uncontrollable and may be considered random variations in conducting the experiments. These parameters may somewhat affect the quality of Flashing Ball surfaces.

- *Operator's variability* or *subjectivity*
  Uncertainties of human performance are unavoidable. This is the main reason why the outcome of Flashing is generally inconsistent. Examples of operator's variability include lack of knowledge, improper measurement and skill level.
- *Environmental factors*
  A Flashing operation is preferably to be performed in a clean and steady environment. However, this is not always possible. Examples of environment factors include temperature, vibration, and dirt.

Controllable Parameters (Input Parameters)

The controllable parameters used in the experiments are basically process control parameters. These parameters can be categorized into "constants" and "variables". Since the 2^k factorial design is used, there are only two levels for each variable.

(A) CONSTANT:

- Flash ring Plate material - Cast iron is the most widely used material for Flash ring. Balls used in experiment are of stainless steel.
- Flash ring plate diameter - Since there is only one size of Flash ring plate available for the experiments, the Flash ring plate size is a constant here.
- Coolant Type - For the all experiments the coolant used is Polycool 86.
- Coolant Temperature - Coolant temperature is kept constant throughout the process which is kept 25° c for whole operation.

(B) VARIABLE:

- Pressure - In this experiment pressure will be varying & this is 2^k factorial design so there is two values of pressure will be chosen.
- No. Of Grooves - Here no. of groove will also be varied.
- Plate RPM - Two different values of RPM are used in performing this experiment. Plate RPM is believed to be among critical process parameters.

Responses (OUTPUT PARAMETERS)

- Spread in **μm**.

4. Explanation for Experimental Design

To measure the ball diameter dial indicator is used which measures the size of balls is shown in fig 5. Spread is the variation in the diameter of balls of same batch or lot. Spread is the difference between the largest diameter & the smallest diameter of balls from a same lot. Spread is measured as μm.

Fig 5: Dial Indicator

The experiment for Flashing was designed using a full factorial design with two levels for each input variable (2^k factorial design). Since there are three factors, each at two levels, the design is 2^3 factorial design which requires

8 runs to complete all the possible combinations. Here the experiment will be having replicates of 2. So for each combination the no of readings are 2. Below table shows the factors and their levels of interests.

Table 2: Factors & levels of interest

Factors	Levels
Pressure	25 Kg/cm^2 & 30 Kg/cm^2
No. of Grooves	15 & 18
RPM of Ring Plate	90 pm & 110 rpm

4.1EXPERIMENTAL RESULTS:

Table 3: SPREAD in μm (BALL DIAMETER VARIATION)

RPM (A)	***NO. OF GROOVES (B)***			
	15		*18*	
	PRESSURE (C)		***PRESSURE (C)***	
	25 kg/cm^2	*30 kg/cm^2*	*25 kg/cm^2*	*30 kg/cm^2*
90	*5*	*8*	*8*	*10*
	6	*9*	*7*	*9*
110	*8*	*9*	*9*	*11*
	7	*10*	*10*	*9*

4.2 Calculation for Spread:

Table 4: 2^3 effect table for Spread

Treatment Combination	***Coded Factors***			***Spread***		***Total***
	A	**B**	**C**	**Replicate 1**	**Replicate 2**	
1	-	-	-	5	6	**11**
a	+	-	-	8	7	**15**
b	-	+	-	8	7	**15**
ab	+	+	-	9	10	**19**
c	-	-	+	8	9	**17**
ac	+	-	+	9	10	**19**
bc	-	+	+	10	9	**19**
abc	+	+	+	11	9	**20**

Sum of Squares:

$SS_A = \frac{(Contarst\ A)^2}{8n} = \frac{(Effect\ Of\ A \times 4n)^2}{8n} = 7.5625$

$SS_B = \frac{(Contarst\ B)^2}{8n} = \frac{(Effect\ Of\ B \times 4n)^2}{8n} = 7.5625$

$SS_C = \frac{(Contarst\ C)^2}{8n} = \frac{(Effect\ Of\ C \times 4n)^2}{8n} = 14.0625$

$SS_{AB} = \frac{(Contarst\ AB)^2}{8n} = \frac{(Effect\ Of\ AB \times 4n)^2}{8n} = 0.0625$

$SS_{AC} = \frac{(Contarst\ AC)^2}{8n} = \frac{(Effect\ Of\ AC \times 4n)^2}{8n} = 1.5625$

$SS_{BC} = \frac{(Contarst\ BC)^2}{8n} = \frac{(Effect\ Of\ BC \times 4n)^2}{8n} = 1.5625$

$SS_{ABC} = \frac{(Contarst\ ABC)^2}{8n} = \frac{(Effect\ Of\ ABC \times 4n)^2}{8n} = 0.0625$

$SS_{total} = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c} y_{ijk}^2 - \frac{y_{...}^2}{8n}$

$= (5^2 + 6^2 + 8^2 + 7^2 + 8^2 + 7^2 + 9^2 + 10^2 + 8^2 + 9^2 + 9^2 + 10^2 + 10^2 + 9^2 + 11^2 + 9^2) - \frac{135^2}{8\times 2}$

$= 37.93$

$SS_{Error} = SS_{total} - SS_A - SS_B - SS_C - SS_{AB} - SS_{BC} - SS_{AC} - SS_{ABC}$

$= 5.4925$

$SS_{Model} = SS_A + SS_B + SS_C + SS_{AB} + SS_{BC} + SS_{AC} + SS_{ABC}$

$= 7.5625+7.5625+14.0625+0.0625+1.5625+1.5625+0.0625$

$= 32.4375$

ANOVA:

Table 5: ANOVA for Spread

Source Of Variation	*Sum of Square*	*Degree Of Freedom*	*Mean Square*	F_0	F_{table} $F_{0.05,1,8}$	*Significant / Insignificant*
A	*7.5625*	*1*	*7.5625*	*11.01*	*5.32*	*Significant*
B	*7.5625*	*1*	*7.5625*	*11.01*		*Significant*
C	*14.0625*	*1*	*14.0625*	*20.48*		*Significant*
AB	*0.0625*	*1*	*0.0625*	*0.09104*		*Insignificant*
BC	*1.5625*	*1*	*1.5625*	*2.2760*		*Insignificant*
AC	*1.5625*	*1*	*1.5625*	*2.2760*		*Insignificant*
ABC	*0.0625*	*1*	*0.0625*	*0.09104*		*Insignificant*
Error	*5.4925*	*8*	*0.6865*			
Total	*37.93*	*15*				

Percentage Contribution:

% Contribution of Factor A (RPM) = $\frac{7.5625}{32.4375} \times 100 = 23.31$ %

% Contribution of Factor B (No Of Grooves) = $\frac{7.5625}{32.4375} \times 100 = 23.31$ %

% Contribution of Factor C (Pressure) = $\frac{14.0625}{32.4375} \times 100 = 43.35$ %

2^3 Design Model

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \beta_{123} x_1 x_2 x_3$$

Where y = Function of Model (Spread),

x_1, x_2, x_3 = RPM, No. of grooves & Pressure respectively.

$\beta_0, \beta_1, \beta_2, \beta_3, \beta_{12}, \beta_{13}, \beta_{23}, \beta_{123}$ = Coefficient

$\beta_0 = \frac{\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c} y_{ijk}}{abcn} = 135/16 = 8.4375$

$\beta_1 = \frac{effect\ of\ A}{2} = 1.375/2 = 0.6875$

$\beta_2 = \frac{effect\ of\ B}{2} = 1.375/2 = 0.6875$

$\beta_3 = \frac{effect\ of\ C}{2} = 1.875/2 = 0.9375$

$y = 8.4375 + 0.6875x_1 + 0.6875x_2 + 0.9375x_3$

Now from the below graphs the value of pressure, RPM, No. of grooves will be at lower level

So, $x_1 = -1, x_2 = -1, x_3 = -1$

$y = 8.4375 + 0.6875(-1) + 0.6875(-1) + 0.9375(-1) = 6.125$

$y_{mean} = 5.5$

so, residual $e = 5.5 – 6.125 = - 0.625$

Now final parameters to achieve minimum spread are,

RPM = 90, Pressure = 25 kg/cm^2, No. of grooves = 15

At above level of these parameters the residual is also -0.625. So, fitted regression model is true for these levels.

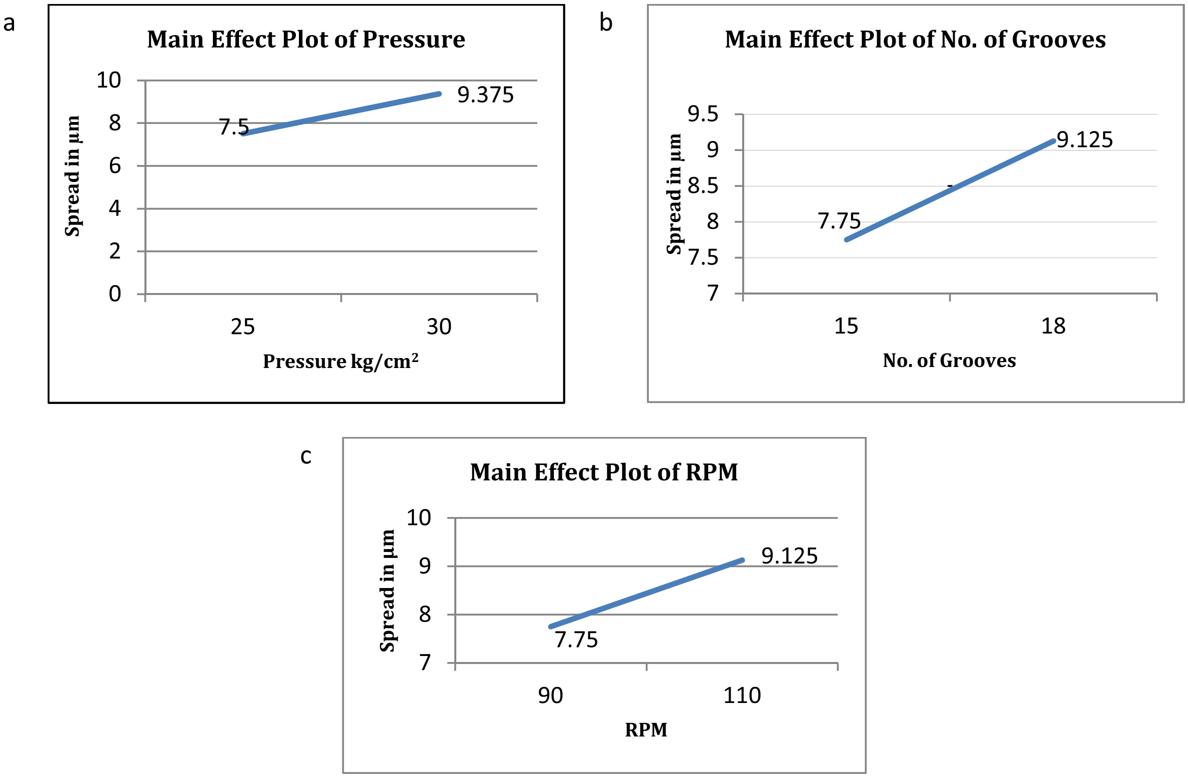

Fig 6 (a) Spread vs Pressure, (b) Spread vs No. Grooves , (c) Spread vs RPM

5. CONCLUSION:

From the DOE for the Spread gives that only the main effects of parameters are significant, interaction effect are insignificant. Percentage contributions are pressure having 43.55%, No. of Grooves having 23.31% & RPM having 23.31% effect on spread. Here the aim is to reduce the spread. So from the main effect plot of Spread Vs Pressure (Figure 5 a) pressure should be at lower level. Same way from (Figure 5 c) RPM should be at lower level & from (Figure 5 b) No. of grooves should also be at lower level to achieve minimum spread. So for minimum spread pressure will be 25 kg/cm^2, plate speed 90 rpm & No. of grooves are 15. Also the residual found at this level from the regression model is – 0.625 which is very less.

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